ROTORCRAFT HEALTH MANAGEMENT ISSUES AND CHALLENGES

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OVERVIEW

- Background
- Standard Practices
- Lessons Learned
- Future Challenges

BACKGROUND

In **Rotorcraft,** the propulsion system is used for lift, propulsion and flight maneuvering.

Helicopter safety is heavily dependent on the reliability and integrity of the power train.

This paper focuses on health management issues related to the dynamic mechanical components in the power train.

BACKGROUND

Rotorcraft Accident Statistics

Survey of rotorcraft accidents from 1937-1981 due to fatigue fracture found 32% caused by damaged engine and transmission components.

Study of 1168 accidents from 1990-1996 found structural failures the 2nd most common cause of accidents.

Continuation of this study from 1998-2004 found failure of the propulsion system the primary cause of vehicle related accidents.

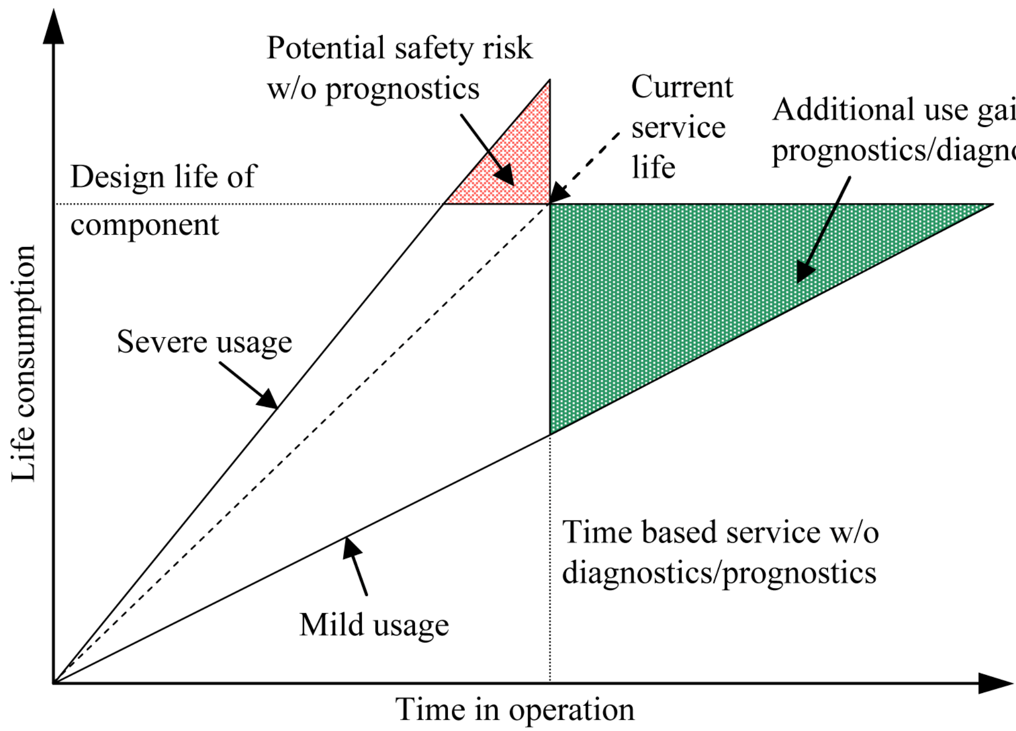
1999 world total of 192 helicopter accidents, found 28 directly due to mechanical failures with the gearbox drive train most common.

BACKGROUND

Economic & Safety Benefits of Diagnostics & Prognostics

Reference: Romero, Summers and Cronkhite, 1996 .

- Service life extended if actual usage lower than predicted
- Safety benefit if actual usage more severe than predicted



BACKGROUND

Current Status of Commercially Available Health Usage Monitoring Systems (HUMS)

- Starting to provide safety and economic benefits
- CAA (UK Civil Aviation Authority) shows a 70% fault detection rate in fielded HUMS
- Historic average false alarm rates of 1 per 100 flight hours

STANDARD PRACTICES

Vibration-Based Methods

- Damage in transmission components produce changes in vibration signatures.
- Various vibration signature analysis methods developed to detect damage to bearings, gears, etc.
- Gears produce vibration signals synchronous with speed.
- Noise in their signal area reduced using time synchronous averaging.

STANDARD PRACTICES

Vibration-Based Gear Fault Detection Methods

Reference: Zakrajsek, 1989 and 1994.

Time synchronous averaged (TSA)vibration data

↓

Fast Fourier Transform

↓

FM4

Gear Meshing Frequency Harmonics, 1st Order Sidebands

Filter

NA4

Gear Meshing Frequency, Harmonics

↓

Inverse Fast Fourier Transform

↓

Difference Signal(Filtered TSA)

↓

Kurtosis/(Std. Dev. Of Diff. Sig.)^4 averaged

STANDARD PRACTICES

Vibration-Based Bearing Fault Detection Methods

Reference: Howard, 1994

- Fault/defect frequencies (calculated by bearing dimensions and speed) generated when bearing fails.
- Several methods exist for extracting bearing defect frequencies from vibration data.

Time domain:

- Statistical parameters: RMS, peak, kurtosis

Frequency Domain:

- FFT used to identify characteristic bearing defect frequencies and their change in amplitude.
- Envelope analysis used to identify bearing resonances excited by periodic impacts (correlate to defect frequencies) when defect contacts another bearing surface.

STANDARD PRACTICES

Metrics Evaluation Tool

Reference: Safa-Bakhsh, Byington, Watson, and Kalgren, 2003.

- Need to evaluate performance of vibration-based fault detection methods for damage detection and false alarms.
- Metrics Evaluation Tool developed by Boeing to evaluate fault detection methods using probability of detection, false alarm metrics and diagnostic accuracy metrics.
- Database required to store vibration data collected from multiple gearboxes for analysis with existing diagnostic algorithms.
- To date, a complete database of vibration algorithms and their capabilities or limitations does not exist due to the limited amount of transmission fault data available.

STANDARD PRACTICES

Environmental Effects on Fault Detection Methods

References: Larder, 1997; Zakrajsek and Dempsey, 2001; Huff, Mosher and Dempsey 2003.

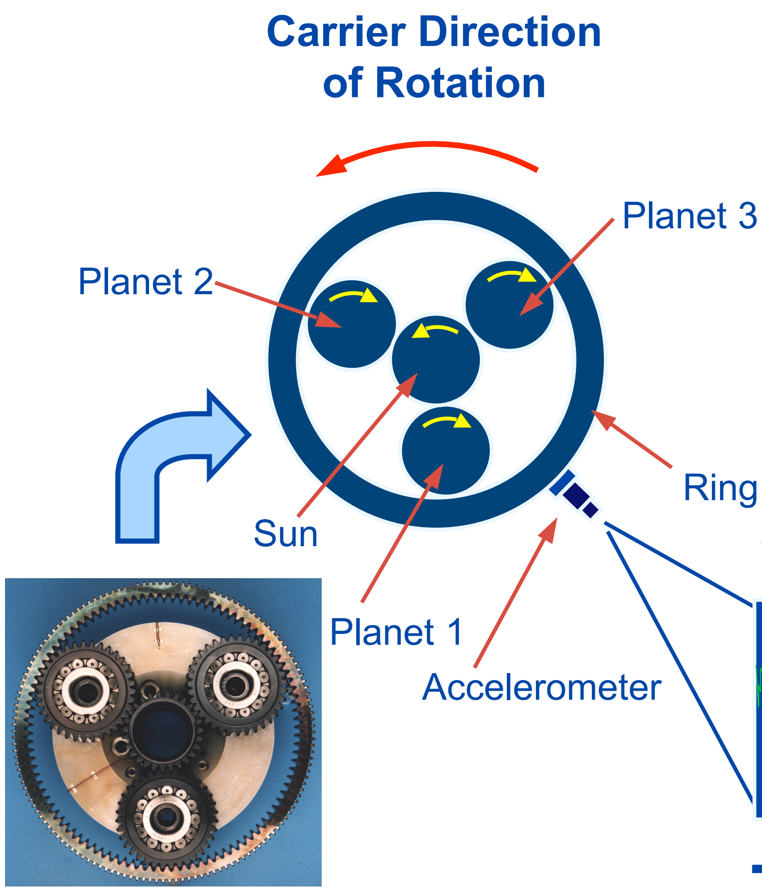
- Sensitivity of the diagnostics to environmental effects required for utilizing HUMS in varying flight regimes.
- HUMS manufacturers have observed significant variances of indicator levels between gearbox components.
- Due to limited damage data in flight, diagnostic tools must be developed in controlled ground test environments.
- Thresholds defined in test rigs can be used to define thresholds in flight to correctly classify the transmission operation as normal.
- Flight fault data is required to verify damage detection sensitivity demonstrated in test rigs can be maintained in flight.

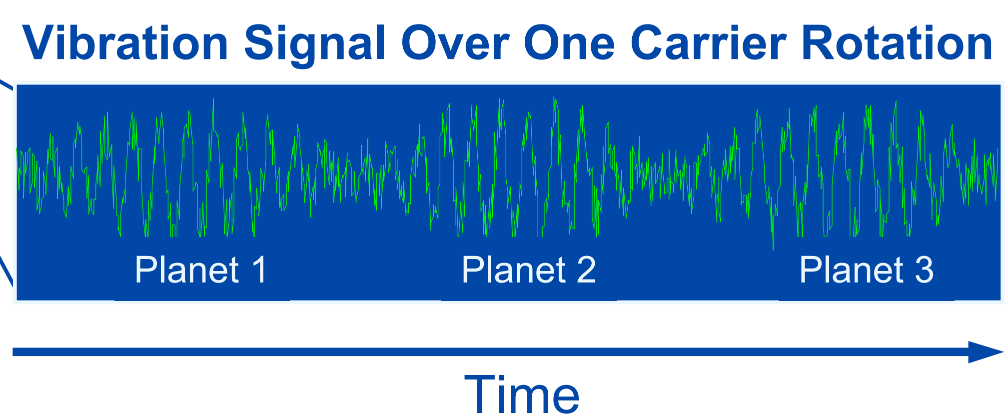
STANDARD PRACTICES

Vibration Based Planet Carrier Fault Detection Methods

References: Samuel and Pines, 2003; McFadden, 1991; Mosher, 2005; Garga, 2005.

- As the transmission rotates, each individual planet passes the sensor.
- When a given planet gear is near a sensor, the vibrations measured by the sensor are dominated by the meshing of the planet gear with the ring gear and the sun gear.
- **Goal:** Develop a method for separating vibration signatures of individual sun, planet, and ring gears.





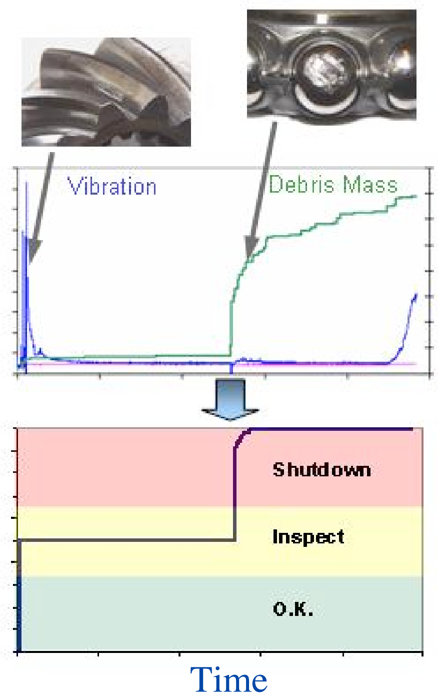
STANDARD PRACTICES

Data Fusion

References: Dempsey, Handschuh, and Afjeh 2003.

Fusing oil debris analysis and vibration data, instead of relying only on vibration, has shown great promise for improving damage detection and decision-making capabilities in current HUMS.

- Wear debris and vibration signatures generated during failures.
- Data fusion concept validated in ground tests on Spur/Spiral Bevel Gear and 500-HP Transmission gears and bearings.
- Improved diagnostic tool performance using fused system over individual features.



LESSONS LEARNED

Challenges to improving HUMS performance
Eurocopter's list of shortfalls

Reference: Pouradier and Trouvé, 2001.

Shortfalls/Difficulties	Reasons identified
Integration with operator's maintenance and logistics	1.System complexity 2.New operator skills
Limited maintenance credits •Limited maintenance alleviation •Time Between Overhauls unchanged	Performance •Lack of evidence of performance •Incomplete defect coverage •Limited prognosis performance
Some mechanical damage is still missed •Monitoring of epicyclic stages to be improved •Some damage is never or is inconsistently detected	Performance •Incomplete defect coverage

LESSONS LEARNED

Eurocopter's list of shortfalls (cont.)

Shortfalls/Difficulties	Reasons identified
Operating cost higher than anticipated •Decision making sometimes difficult	Performance •Limited diagnosis performance because of not "defect specific" monitoring techniques
Acquisition cost •Most of the Civil applications in the North Sea sector •HUMS mostly installed on heavy aircraft	Technology •Not enough standardization •Difficulty in retrofitting HUMS •Rapid obsolescence
Support cost higher than anticipated •Long maturing process •Help for diagnostics •Threshold adjustment •Continuous development	Performance •Monitoring techniques not "defect specific"

LESSONS LEARNED

Smiths Aerospace HUMS

Maintenance and improved operational benefits from 300 HUMS

- Operational service in the UK Chinook fleet since 2000
- Accurate record of helicopter usage for maintenance and lifing
- Reduced consequential damage from a mechanical fault
- Improved aircraft troubleshooting
- Reduction of unscheduled maintenance
- Maintenance credits and extension of component life
- Performs fleet wide health check monitoring of all HUMS equipped aircraft for a specific fault in a short amount of time

LESSONS LEARNED

Review of 180 HUMS-related maintenance actions

Canadian Forces Maintenance Program for CH-146 Griffon Fleet

- Enabled maintenance following an exceedance (41%)
- Installation improvements precluded accelerated wear (19%)
- Precluded the need for additional troubleshooting (17%)
- Precluded expensive (+$100K) component replacement (12%)
- Possibly prevented serious faults (11%)

LESSONS LEARNED

Goodrich Integrated Mechanical Diagnostics Health and Usage Management System (IMD-HUMS)

- Demonstration of the IMD-HUMS with the Army achieved 58% maintenance man-hour reductions compared to current practices.
- Results from 3 U.S. Marine CH53E and 30 U.S. Army UH-60L helicopters showed the IMD-HUMS was able to detect a number of mechanical anomalies.
- The IMD-HUMS system has provided more specific diagnostic information than previously available with standard techniques.
- Setting accurate threshold levels for the various health indicators is a challenge.

LESSONS LEARNED

Vibration Management Enhancement Program (VMEP)

- Installed on over 100 helicopters
- Developed a large database of drive train diagnostic indicators of faults on critical areas of the drive train
- A web-based system for statistical analysis of Army HUMS parameters from over 100 aircraft is used to let engineers set condition indicator limits from remote locations

FUTURE CHALLENGES

- Increase the fault detection coverage from today's rate of 70 %
- Increase the reliability of damage detection
- Decrease false alarm rates from historic average rates of about 1 per 100 flight hours by an order of magnitude
- Develop technology to accurately detect on-set of failure and isolate damage, and assess severity of damage magnitude
- Develop life prediction technologies to assess effects of the damage on the system and predict remaining useful life and maintenance actions required
- Integrate the health monitoring outputs with the maintenance processes and procedures

FUTURE CHALLENGES

- Develop data management and automated techniques to obtain and process diagnostic information with minimal specialist involvement
- Develop system models, material failure models and correlation of failure under bench fatigue tests, seeded fault tests and operational data
- Development of a generic data collection and management scheme for analysis of operational data (Establishing threshold, false alarm and detection rates requires a large body of data with rich statistical content)
- Development of mature and verifiable techniques to detect catastrophic failures and give in-flight pilot cueing and warning in near real-time